The coastal habitats and vegetation of the Kimberley region

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Abstract

Incorporating the areas of the rocky Kimberley Coast, flanked by the deltaic gulfs of Cambridge Gulf and King Sound, as well as the Dampier Peninsula, the Kimberley region host a complicated coastal zone with a plethora of coastal habitats. The smallest scale of habitat includes rocky cliff, scree slopes, gravelly/bouldery shore, sandy beaches, spits, dunes, tidal mud flats, alluvial fans, and the contact between some of these habitats and freshwater. The main vegetation units include mangroves, shrubby chenopods (which include succulent halophytic shrubs), saline marsh, sedgelands, rushlands, dune scrub, dune grasslands, and teatree thickets. The spatially and temporally variable landscape, sediments/soils, and hydrochemistry expressed at the coast mean that the coastal vegetation habitats are the most complex habitats in the Kimberley region. This review found that to date these have not been fully explored or described botanically.

Keywords: Kimberley Coast, coast, coastal habitats, mangrove, saltmarsh, mangal, chenopod

Introduction

Perhaps the first general survey of coastal ecosystems in Western Australia was Sauer (1965), which dealt, *inter alia*, with the Kimberley coast. While there have been a limited number of works published focusing specifically on the flora and vegetation of the Kimberley region most of these have focused on specific habitats and formations such as the Kimberley Rain Forests (McKenzie *et al.* 1991), or on regions such as the Dampier Peninsula (Kenneally *et al.* 1996), Drysdale Nature Reserve (Kabay & Burbidge 1977), the Prince Regent River Nature Reserve (Miles & Burbidge 1975), Bougainville Peninsula, Osborn and Institut Islands (Beard *et al.* 1984), and Mitchell Plateau/Admiralty Gulf (Wells 2006). Flora and vegetation have also been noted in the studies of landforms of the Kimberley region undertaken by the Agricultural Department and the CSIRO (*e.g.*, Speck 1960; Speck *et al.* 1964), and more regional surveys and characterisations such as that undertaken by Beard (1979). Furthermore key works have been published that provide diagnostic and ecological data on the flora (Wheeler *et al.* 1992), or checklists of presence of plant species within the Kimberleys (Kenneally 1989). However, to date, apart from studies of mangroves and saline marsh (Wells 1979 1981; Semeniuk 1980, 1983, 1985; Bridgewater 1982, 1985, 1989; Bridgewater & Cresswell 1993, 1999, 2003, Cresswell & Bridgewater 1998), there has been little focus on flora and vegetation specific to the coastal zone. The coastal zone is the most classic ecotone, where a wide range of environmental factors combine to provide templates and stimuli for the development of complex mosaics of plant communities.

While vegetation (and flora) of the 'inland' Kimberley region can be related clearly to underlying rock formations, soils, water availability, and climate; in the coastal zone vegetation distribution (and its component flora) responds to a wider variety of environmental factors including physiography, groundwater characteristics and climate, together with the effect of sea spray. Variation in the climate, landforms, soils, and habitats of the 'inland' Kimberley Plateau, for instance, does result in complex vegetation, including some very specific micro-climate controlled habitats, or those where there is freshwater seepage on basalt slopes and vine thickets are developed; or the narrow deeply incised valley tracts with local freshwater springs where *Pandanus* dominated wetlands are found.

In general, the 'inland' Kimberley Plateau vegetation is relatively consistent across its 16,000 square kilometres of sandstone and basalt plateaux (Griffin & Grey 1990a, 1990b) compared to the coastal zone. Similarly there is a relative consistency across the Dampier Peninsula of a relatively uniform geology (Gozzard 1988). The greatest environmental determinant of vegetation distribution across these inland terrestrial environments across the entire region is rainfall and water availability. The Kimberley coastal zone, however, is more variable spatially and temporally, and this variability is expressed through complex vegetation patterning. It is spatially variable because, as an ecotone between terrestrial and marine environments, it is subject to marine processes that are variably developed along the coast, (*i.e.*, different wave energy, tides, orientation of coast, sediment supply, sediment type, and coastal landforms) resulting in a wide range of coastal physiographic templates: sea cliffs, beaches, dunes, tidal flats, muddy embayments, amongst many others. The coastal zone exhibits greater temporal variability in habitat development because it is subject to marine processes that can create, modify and destroy habitats (*e.g.*, the development of barrier sand bars, dune formation, and collapse of sea cliffs, amongst others). The study of the flora and vegetation of the Kimberley coastal

zone provides opportunity to identify ecological patterns and set a framework for understanding broad biogeography, which in turn informs conservation policy.

A number of authors refer to vegetation that inhabits coastal settings in the Kimberley region, but the descriptions have not been focused specifically on the coastal effects on determining vegetation and its composition. For instance, Hnatiuk & Kenneally (1981) recognise 'Cliff Face Communities' as a distinct vegetation unit in the region, however they do not differentiate those which are coastal facing and subject to marine influences from those that are further inland. On the other hand, where there is recognition of coastal habitat, it is too broad, and not related to a specific habitats; *e.g.*, Hnatiuk & Kenneally (1981) recognise a 'Strandline Communities' containing a limited set of species including small trees, climbers and graminoids, but it is difficult to ascertain what exactly constitutes a strandline, and whether it incorporates habitats such as beach crest, salt flat edge, bouldery shores, cliff shores, chenier margin, amongst others. Kenneally *et al.* (1991) in a study of floristics of rainforests in the Kimberley region record some occurrences of vegetation types at the coast, however, given the stratigraphic and hydrological underpinning of the occurrence of the rainforests, their analysis did not differentiate whether these coastal occurrences are just stratigraphic and hydrologic manifestations of the habitat at the coast or whether the rainforest is structurally or floristically distinct from inland rainforest.

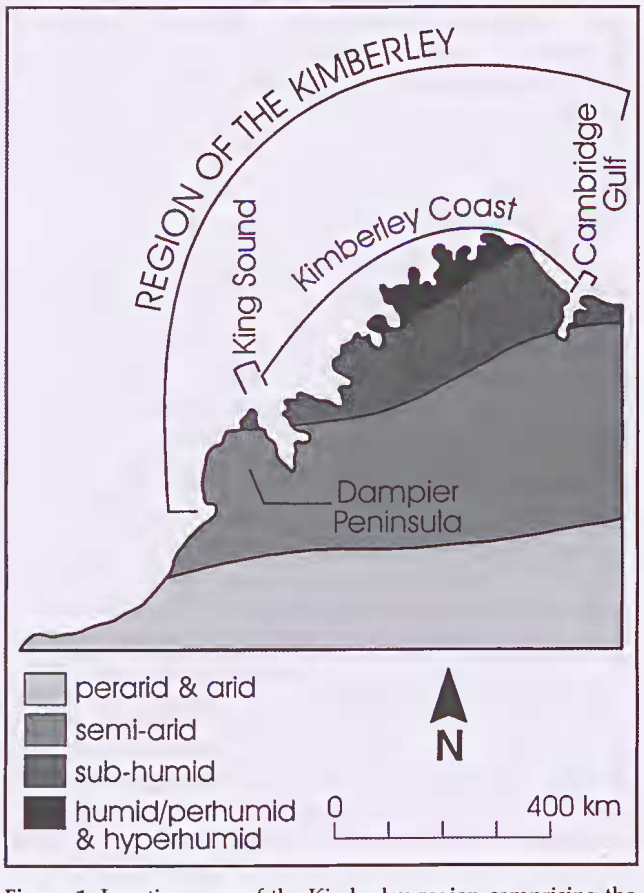

Figure 1. Location map of the Kimberley region comprising the Kimberley Coast, King Sound, Cambridge Gulf, and the Dampier Peninsula, and their climate setting.

McKenzie *et al.* (1991) undertook a quantitative analysis of the floristic and faunistic composition of a set of representative samples of Kimberley rainforest patches. This revealed only one type that was restricted to near-coastal locations (within which only one group had not been extensively damaged by cattle, consisting of a low scrubby patch on an isolated Quarternary coastal sand dune towards the seaward edge of an extensive tidal mudflat in the far northeastern Kimberley). However, because of a correlation between annual rainfall and proximity to the coast in the North Kimberley, the analysis also showed that scree slope and riparian patches near to the coast were larger and had a wider array of species than their inland counterparts (McKenzie *et al.* 1991, McKenzie *pers. com.* 2011).

Kenneally *et al.* (1996) in a study of the Dampier Peninsula characterise some of its coastal vegetation into broad habitats such as seepage zones, coastal dunes, and limestone outcrops, and lists some of the vegetation in structural terms such as saline grasslands, samphire (shrubby chenopods in our terms) flats and mangroves, as well as some lists of key species that characterise the habitats or vegetation formations.

As part of this Symposium on the Kimberley marine and coastal environments we have endeavoured to review the information on the flora and vegetation of the Kimberley region (Fig. 1), through the lens of our own data and experiences, and present a broad description of the coastal habitats and vegetation of the Kimberley region.

The objectives of this paper are to describe the abiotic habitats (the geological, landscape and climate-determined templates of vegetation), set these various habitats within the major geological/physiographic subdivisions of the Kimberley region, describe the broad phytogeography and, as the limits of literature and our experience permit, describe some of the main elements of the Kimberley vegetation as it responds to geology, landscape, and climate in the coastal zone.

Terms and methods

"Coastal" means that environment that is the land-sea interface, and is inundated by tides or is influenced by maritime processes such as salt spray, storm surge *etc.* We include in coast the strip of land between terrestrial and marine environments, between low tide and high tide, as well as the area adjoining the marine environment that is still influenced by maritime processes, *e.g.*, salt spray, sea-derived winds, and cyclone-elevated sea levels, and those habitats formed in the very recent past by coastal processes but now are above prevailing high tide. The definition of 'coastal zone' is relatively straightforward where there are sea cliffs, sand dunes, and a distinct high-tidal mark, but is more difficult where broad alluvial plains grade into the coastal zone.

Defining 'coastal vegetation' is more difficult. Vegetation that is inundated by tides, or that which occupies saline or hypersaline conditions, or preferentially inhabits the zone of sea spray and salt-bearing winds, can be assigned to the category of 'coastal'. However vegetation or species inhabiting the

strandline, or a sea-facing cliff, does not mean that vegetation or a species is purely 'coastal' if they also occur inland in the same composition. Rainforests illustrate this principle: the composition and structure of rainforest inhabiting soil-moist slopes of basalt that adjoin cliffs of fractured sandstone inland may be the same as that along ocean-facing cliffs. Only rainforest that compositionally or structurally reflects maritime condition is 'coastal'. Figure 2 presents several examples of vegetation growing at the coast which is not by our definition 'coastal'.

The study of the habitats and vegetation of this coastal region is based on literature review and our own extensive field work and sampling sites as noted in Bridgewater (1982, 1985, 1989), Bridgewater & Cresswell (1993, 1998, 1999, 2003), Cresswell & Semeniuk 2011), Semeniuk (1980, 1983, 1985 1986, 2008, 2011).

The study area – what do we mean by the 'Kimberleys'?

The Kimberley region has various definitions. Administratively, and in more general usage, the Kimberley region extends from the Northern Territory border (the eastern Kimberley), across the plateaux (the Kimberley Plateau) between Cambridge Gulf, Fitzroy River and King Sound, to the Dampier Peninsula as far south as Eighty Mile Beach. Reflecting its climate setting the 'Kimberleys' are a much smaller area, encompassing the eastern Kimberley, the Kimberley Plateau(x), the Fitzroy River valley tract, King Sound, and the Dampier Peninsula. Geologically and physiographically it is even smaller, and the Kimberley geological region consists of the Kimberley Plateau and the bordering McLarty Ranges (the area of the Dampier Peninsula and King Sound belong to the Canning Basin, whereas Cambridge Gulf is part of the Bonaparte Gulf Basin and the Halls Creek Province).

Given the major influence of climate as a driver of the distribution of biota, the Kimberley region biogeographically commonly is delineated on its broader definition (and not solely based on geological precepts). Using this broader definition of the Kimberley region adopted for this Symposium, it is useful to delineate the four geological and physiographic units and their coastal expressions, namely, from north to south:

1. Cambridge Gulf, comprising coastal units of alluvial plains, rocky ranges, and broad tidal flats;
2. Kimberley Coast (*sensu* Semeniuk 1993), comprising coastal units mainly of rocky shores, ria embayments, sandy coves;
3. King Sound Gulf, comprising coastal units of alluvial plains, red sand dunes, and broad tidal flats;
4. Dampier Peninsula, comprising coastal units on its western side of sea cliffs, tidal embayments, sandy coves and sandy barriers.

These units will form the natural large scale physiographic units within which we will place the various smaller scale coastal habitat templates. The coastal distribution of these units is shown in Figure 1.

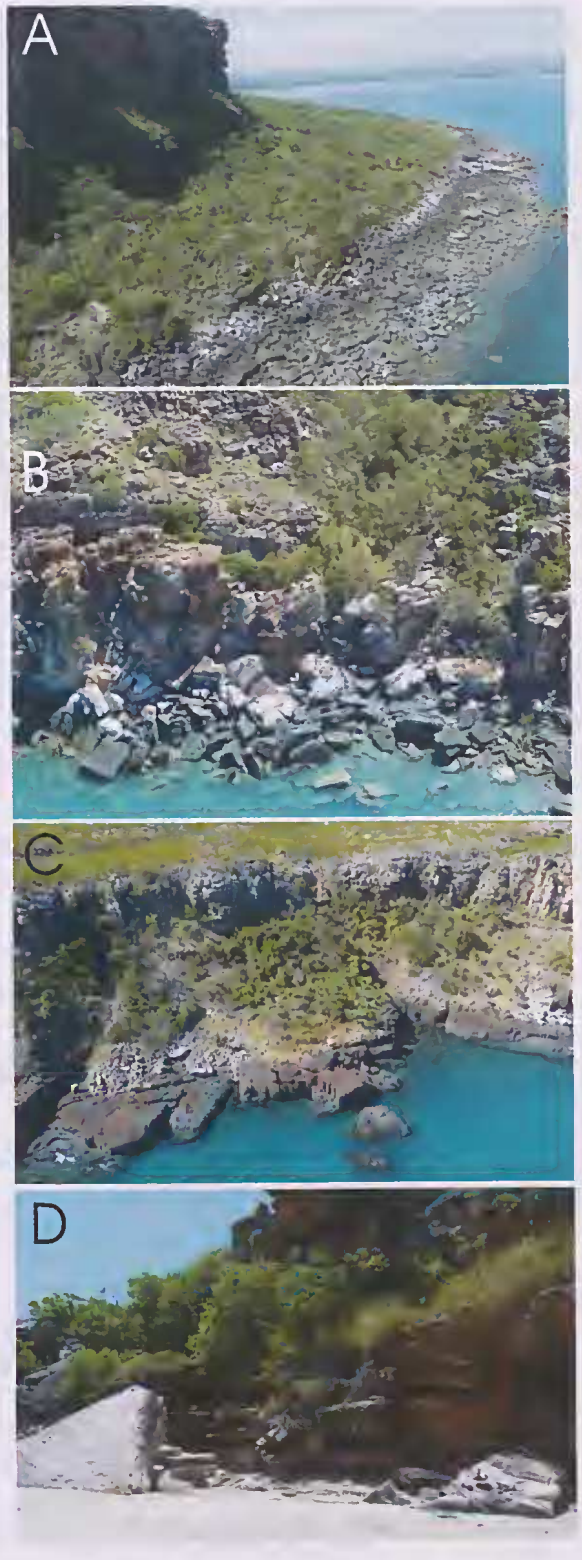

Figure 2. Examples of terrestrial vegetation at the coast. A. Steep vegetation-free cliff truncating the terrestrial vegetation at the top; slope is vegetated by scree vegetation; thin bleached zone is the level of the highest tides; boulder tidal zone is mangrove free. B. Terrestrial vegetation (plateau top and valley type) truncated at cliff, a crumbling cliff; bleached zone is the level of the highest tides. C. Terrestrial vegetation truncated at cliff; scree slope with scree vegetation; *Triodia* almost to the foot of the scree; bleached zone is the level of the highest tides. D. *Triodia* on cliff face; brown zone of rock face is above the level of the highest tides and all vegetation is terrestrial; top of bleached zone is the level of the highest tides.

Table 1

Main habitats of the coastal zone (scale of reference modified from Semeniuk 1986)

Major geological/ physiographic unit (regional scale)	Large scale landforms	Medium to small scale landforms (= physiographic habitats), in general order of abundance
Cambridge Gulf	alluvial plains, rocky ranges, broad tidal flats	tidal mud flats, rocky cliffs, sandy beaches, sandy cheniers, coastal scree slopes
Kimberley Coast	rocky shores, rias, embayments, sandy coves, sandy barriers	rocky cliffs, terraced cliffs, coastal scree slopes, gravelly/bouldery shores, tidal mud flats, sandy beaches, sandy cheniers, sandy spits, dunes, alluvial fans, alluvial fan to tidal flat freshwater interface, rocky slope and salt flat freshwater interface, dune to tidal flat freshwater interface, beach rock ramps
King Sound	alluvial plains, red sand dunes, and broad tidal flats	tidal mud flats, sandy beaches, sandy cheniers, sand cliffs, red sand dune freshwater seepage zones
Dampier Peninsula	sea cliffs, tidal embayments, sandy coves, sandy barriers	rocky cliffs, sandy beaches, beach rock ramps, alluvial fans, alluvial fan to tidal flat freshwater interface; dune freshwater seepage zones; freshwater ponds

Table 2

Description of habitats and occurrence of vegetation

Habitat unit	Description of habitat
rocky cliff	coastal rock face that may be vertical or steeply inclined, and with terraces; if terraced, smaller scale aprons of scree separate the vertical faces; scree slopes are gravel, sandy gravel, and muddy gravel; rock may be sandstone or basalt
terraced cliff	coastal rock face (usually a sandstone/basalt contact) that is prominently terraced, with or without scree separating the vertical faces; faces are vertical or steeply inclined; smaller scale aprons of scree separate the low vertical faces; scree slopes are gravel, sandy gravel, and muddy gravel
coastal scree slope	scree slopes of gravel, sandy gravel, and muddy gravel
gravelly/bouldery shore	steep to moderately sloping rocky tidal surface with veneer of gravel and boulders
sandy beach, sandy chenier, sandy spit dune	moderately sloping to hummocky sandy tidal surface, rising upslope to supratidal and passing into dunes hummocky sandy terrain, above tidal levels
coastal dune barring drainage or freshwater seepage	depression or swale between coastal dunes and the hinterland where freshwater drainage or freshwater seepage from the land is barricaded to form a shore-parallel wetland; this is the area where coastal vine thickets may be developed
sand cliff	cliff cut into sand dune, particularly Pleistocene red sand dunes that are more cohesive to cliff erosion; steep sandy slope or face
limestone cliff	cliff cut into Holocene or Pleistocene limestone dune
tidal mud flat	low gradient tidal muddy surfaces; high tidal zones are commonly hypersaline and thus salt flats
alluvial fan	low gradient gravelly to sandy to muddy surfaces at EHWS
alluvial fan to tidal flat freshwater interface	sharp interface between alluvial fan and salt flat where there is freshwater seepage from the alluvial fan diluting the salt flat hypersalinity
rocky shore and salt flat freshwater interface	sharp interface between rocky slope and salt flat where there is freshwater seepage from the rocky uplands diluting the salt flat hypersalinity
red sand dune to tidal flat freshwater interface	low-gradient interface between red sand desert linear dunes and salt flat where there is freshwater seepage from the dune sand diluting the salt flat hypersalinity
dune to tidal flat freshwater interface	sharp interface between coastal dunes and salt flat where there is freshwater seepage from the dune sand diluting the salt flat hypersalinity
beach rock ramp	moderately sloping rock pavement tidal surface, rising upslope to supratidal sand and locally passing into dunes; mangroves may inhabit the tidal slope seaward of the ramp
freshwater pond	rounded to oval freshwater ponds along the high tidal zone; excavated by solution of carbonate muds

Superimposed on the geological grain of the region and the large scale physiographic units is climate (Fig. 1). In this part of Western Australia, the most humid region is centred on the near-coastal and coastal areas of the north-western Kimberley region in the Mitchell Plateau area. Gradational from this region in northerly and southerly directions, the climate is subhumid and semiarid, respectively. Another factor in the development of habitats and occurrence of biota along the coastal zone is drainage, which is the delivery to the coast of water via local freshwater seepage zones, and rivers, creeks and rivulets.

The major coastal habitats

Within the four major natural geological and physiographic units listed above, there are a large range of smaller scale coastal habitats, delineated by their abiotic characteristics of landforms, sediments/ soils, water features, salinity, and exposure to salt spray. Table 1 provides an hierarchical framework classifying the main habitats of the coastal zone. At the largest scale the major geological/ physiographic units relate to an expression of the geology and physiography of the landscape at the regional scale, generally measured in hundreds of kilometres. Beneath that large scale landforms are an expression of physiographic form generally at the 50–10 km frame. The finest scale landforms (medium to small scale) relate to the expression of landforms as physiographic habitats generally in frames of 1 km down to 100–10 metres.

The geological/physiographic unit containing the greatest number of smaller scale coastal habitats is the Kimberley Coast. A description of smaller scale coastal habitats is presented in Table 2. A selection of key coastal habitats is illustrated in Figure 3. The description of the smaller scale habitats which determine vegetation are not described to the next level of detail (*i.e.* the gradients internal to the habitat in terms of salinity, inundation frequency, and distance from shore and hence sea spray and salt-laden winds).

Coastal Vegetation

Broadly, coastal vegetation in the region can be divided into mangroves, shrubby chenopods (which include succulent halophytic shrubs), saline marshes, sedgelands and rushlands, dune scrub, dune grasslands, and Teatree thickets. Vegetation of coastal habitats is divided into two zones: that located in the tidal zone and that which is supratidal, *i.e.*, straddling the high tide mark, and that above the high tide mark but subject to salt spray, coastal wind, and storm surges. Some key indicator species of the vegetation in these habitats are provided in Table 3. We have emphasised the mangrove and saline marsh species because these systems have had the most attention. Future work is clearly needed on cliff vegetation, and the ecotones between coastal and terrestrial vegetation. A selection of coastal vegetation from the Kimberleys is illustrated in Figure 4.

Previous descriptions of the vegetation of the tidal flats, alluvial fans, gravelly and bouldery shores.

The combination of abiotic habitats described above form the basis for some of the most characteristic and extensive coastal-specific vegetation in the Kimberley region, namely; mangal forest, mangrove or chenopod shrublands and associated wet or often-dry saline marshes.

Bridgewater & Cresswell (1999), describe the region as the Dry tropical Camptostemon-Avicennia-Batis Division in an Australia-wide analysis of mangrove and saltmarsh. They recognise the Kimberley as an important region in the Australian mangrove distribution. While not as species-rich or lush as the north eastern or northern Australian mangrove systems, the Kimberleys have a high level of vegetation heterogeneity in response to the high diversity of coastal abiotic habitats described above. Similarly, Bridgewater (1985, 1989) identifies a number of mangrove and saline marsh communities in the region. At the highest level the following phytosociological classes are described in Bridgewater (1989) Avicennietea, Avicennio-Ceriopetea from eulittoral to supralittoral, and where there is saline marsh this is represented by the Halosarcio-Avicennietea.

There are a large number of communities possible, and in any particular location, there is a wide range of width and extent of vegetation to develop. Extent of freshwater seepage from land, and the nature of substrate are the other two key variables influencing vegetation expression. From eulittoral to supralittoral the key defining species of (often monospecific) vegetation communities are *Sonneratia alba* (especially in the north of the region), *Avicennia marina, Rhizophora stylosa, Aegialitis annulata* (most frequently lining tidal creeks), *Camptostemon schultzii -Bruguiera exaristata, Xylocarpus moluccensis-Ceriops tagal- Lumnitzera racemosa, Excoecaria agallocha -Osbornia octodonta* (especially in more sandy/ rocky areas). In the higher eulittoral to supralittoral range the following are typical *Ceriops tagal, Excoecaria agallocha,* and in hypersaline dry flats stunted *A. marina* with shrubby chenopods.

At the highest supralittoral levels, where freshwater seepage is rare or absent the following are typical *Tecticornia halocnemoides* ssp. *tenuis, Tecticornia indica* subsp. *leiostachya, Suaeda arbusculoides and Batis argillicola.* Depending on the substrate, a flora dominated by graminoids may also develop (*Sporobolus virginicus, Xerochloa imberbis,* and various cyperoid species).

In areas where there are extensive open mud flats the Tecticornietea (Bridgewater, 1989) occurs. This is a simple, annual vascular plant community dominated by *Tecticornia verrucosa.* The mud surface is however covered also by extensive algal flora, including many diatom species.

The determinants for the complex range of vegetation types described above are substrate, distance and slope from eulittoral to supralittoral, and the influence of freshwater flow or seepage. The relatively depauperate flora combines in a number of distinct and identifiable communities, determined by the expression of these physical variables in the many different habitats that are

Table 3

Occurrence of vegetation with respect to coastal habitats

Habitat unit	Some key indicator species
rocky cliff	*Sesuvium portulacastrum; Ficus spp.*[1], *Scaevola taccada, Thespesia populneoides*
terraced cliff	*Sesuvium portulacastrum; Ficus spp.*[1], *Scaevola taccada, Thespesia populneoides*
coastal scree slope	*Sesuvium portulacastrum; Ficus spp.*[1]
gravelly/bouldery shore	*Avicennia marina*[2], *Ceriops tagal, Excoecaria agallocha, Lumnitzera racemosa, Rhizophora stylosa,* and *Sonneratia alba;* supralittoral may have areas of saline slopes with *Sporobolus virginicus, Tecticornia halocnemoides* subsp. *tenuis, Frankenia ambita, Suaeda arbusculoides, Sesuvium portulacastrum*
sandy beach, sandy chenier, sandy spit	The vegetation is patchy with tree, shrub or low shrub/graminoid dominated patches, with a range of species possible: *Avicennia marina, Rhizophora stylosa, Ceriops tagal, Osbornia octodonta, Bruguiera exaristata,* and *Aegialitis annulata; Spinifex longifolius, Fimbristylis cymosa, Fimbristylis sericea, Cyperus bulbosus, Ipomoea pes-caprae* subsp. *brasiliensis, Suaeda arbusculoides, Euphorbia myrtoides, Euphorbia plumerioides, Acacia bivenosa, Lysiphyllum cunninghamii, Canavalia rosea, Scaevola taccada,* and *Thespesia populneoides*
dune	*Spinifex longifolius, Fimbristylis cymosa, Fimbristylis sericea, Cyperus bulbosus, Ipomoea pes-caprae* subsp. *brasiliensis, Salsola kali, Euphorbia myrtoides, Acacia bivenosa, Ficus opposita, Lysiphyllum cunninghamii, Canavalia rosea, Abutilon indicum, Clerodendrum tomentosum, Crotalaria cunninghamii, Hypoestes floribunda, Jasminum didymum, Mallotus nesophilus, Myoporum accuminatum, Ptilotus exaltatus, Santalum lanceolatum, Whiteochloa airoides, Pandanus spiralis*
coastal dune barring drainage or freshwater seepage	coastal vine thickets variable across the region but comprised of *Bridelia tomentosa, Celtis philippensis, Croton habrophyllus, Dioscorea bulbifera, Diospyros hundeyana, Diospyros ferrea* var. *humilis, Diospyros maritima, Exocarpos latifolius, Ficus virens, Glycosmis* spp., *Grewia breviflora, Grewia retusifolia, Melaleuca dealbata, Minusops elengi, Pavetta kimberleyana, Pittosporum moluccanum, Pouteria sericea, Prunna acuminata, Syzygium eucalyptiodes* subsp. *bleeseri, Terminalia petiolaris, Terminalia ferdinandiana* and *Vitex glabrate,* with the vines *Abrus precatorius, Gynnanthera oblongata, Jacquemontia paniculata, Passiflora foetida, Tinospora smilacina* and *Tylophora cinerascens*
sand cliff	*Cyperus bulbosus, Ipomoea pes-caprae* subsp. *brasiliensis, Suaeda arbusculoides, Salsola kali, Euphorbia myrtoides, Euphorbia plumerioides, Scaevola taccada*
limestone cliff	*Ficus spp.*[1], *Scaevola taccada, Spinifex longifolius, Canavalia rosea, Ipomoea pas-caprae brasiliensis*
tidal mud flat	Between MSL and MHWS patchy communities dominated by a range of mangroves including *Avicennia marina, Rhizophora stylosa, Sonneratia alba, Bruguiera exaristata, Aegialitis annulata, Aegiceras corniculatum, Camptostemon schultzii, Bruguiera parviflora, Ceriops tagal, Excoecaria agallocha, Lumnitzera racemosa, Osbornia octodonta, Xylocarpus moluccensis, Xylocarpus granatum,* and at levels between MHWS and EHWS shrubby *Avicennia marina, Batis argillicola, Tecticornia halocnemoides ssp. tenuis, Neobassia astrocarpa, Suaeda arbusculoides, Sesuvium portulacastrum, Sporobolus virginicus, Xerochloa imberbis*
alluvial fan	*Avicennia marina, Bruguiera exaristata, Ceriops tagal, Excoecaria agallocha, Lumnitzera racemosa, (Rhizophora stylosa), Xylocarpus moluccensis, Xylocarpus granatum;* the higher or supratidal range may be covered by saline or brackish marshes, dominated by sedges, grasses, and shrubby chenopods
alluvial fan to tidal flat freshwater interface	Sharp interface between alluvial fan and salt flat where there is inhabited by mangroves *Avicennia marina, Ceriops tagal, Excoecaria agallocha, Lumnitzera racemosa,* or by sedges, grasses, and shrubby chenopods
rocky shore and salt flat freshwater interface	*Avicennia marina, Ceriops tagal, Excoecaria agallocha, Lumnitzera racemosa,* may include also patches of low shrub dominated vegetation
red sand dune to tidal flat freshwater interface	Depending on salinity and location of the contact, *Melaleuca acacioides, Melaleuca cajuputi* and *Melaleuca nervosa,* with an understorey of Cyperaceae (including *Schoenoplectus litoralis*) and graminoids, and locally *Avicennia marina, Lumnitzera racemosa, Tecticornia halocnemoides subsp. tenuis, Frankenia ambita, Suaeda arbusculoides,* and *Batis argillicola*
coastal dune to tidal flat freshwater interface	Heterogeneous patches of vegetation types can be found in this highly diverse abiotic environment, which also exhibits strong temporal variation; typical species or species groups found include *Avicennia marina, Ceriops tagal, Excoecaria agallocha, Lumnitzera racemosa,* various sedges, grasses, and shrubby chenopods
beach rock ramp	*Avicennia marina* and *Ceriops tagal;* mangroves are found on the tidal slope seaward of the ramp; dune vegetation (as above) on the supratidal zones
freshwater pond	Depending on the brackishness of the water *Avicennia marina, Excoecaria agallocha,* and *Lumnitzera racemosa* may inhabit the margins of these ponds, or with fresher states *Melaleuca dealbata, Melaleuca cajuputi* and/or *Pandanus* with Juncaceae and Cyperaceae forming an understorey

[1] It has not been possible to differentiate from the literature those *Ficus* species that occur in coastal settings as *Ficus* species are distributed on rocky screes, ridges and cliff substrate wherever it is available

[2] It is likely both subspecies *marina* and *eucalyptifolia* occur in the Kimberley. The precise ecological segregation of these subspecies, or more importantly undescribed genotypes, remains unclear, but is an area of important future research,

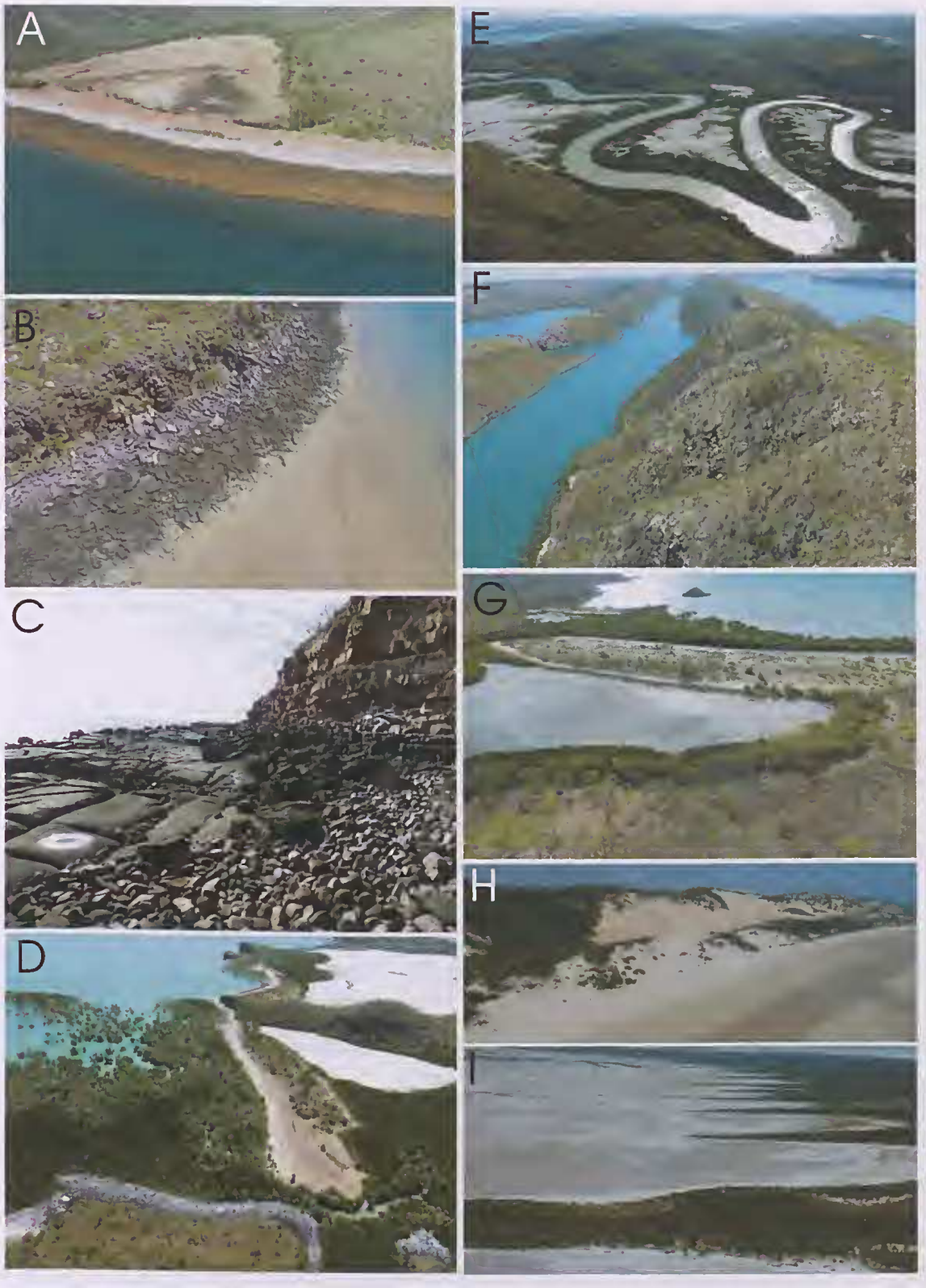

Figure 3. Examples of coastal zone habitats and coastal vegetation. A. Bar and lagoon with mud filled lagoon, hinterland fringed by Teatree (*Melaleuca* spp.), inside of bar with *Melaleuca spp.* and mangroves, crest of bar shrub-covered. B. Terrestrial vegetation truncated at cliff, some vegetation creeping down the cliff and high wave energy labile slope of boulder slabs is vegetation free; bleached zone is the level of the highest tides. C. Vegetation-free cliff with *Triodia* creeping down the top of the cliff and inhabiting ledges. D. Richly patterned habitats of gravel bars, sand bars, gravelly tidal flats, some cliffs; complex mangal vegetation as a result; crest of sand bar is *Pandanus, Melaleuca* spp. and grassy swards of *Sporobolus*. E. Tidal creeks and tidal flats in a valley tract bordered by vegetated terrestrial slopes, resulting in complex mangal and saline marsh vegetation. F. Vegetated slopes of the rocky ridges; bleached zone is the level of the highest tides; mangals in rocky shore tidal zone. G. Bar and lagoon with complex mangal on seaward side of bar, and fringing the hinterland of the lagoon and the inner side of the bar; crest of bar with *Triodia* and shrubs. H. Foredunes and large dunes to landward inhabited by various dune vegetation. I. Linear red sand dunes interfacing with and underlying the salt flat at the level of the highest tides; the vegetation is *Melaleuca* spp., and where freshwater discharges under the salt flat, *Avicennia marina, Melaleuca* spp. or samphires.

Figure 4. Examples of coastal zone habitats and coastal vegetation. A. In the foreground, shrubby chenopod (*Tecticornia halocnemoides* ssp. *tenuis*), with salt tolerant grasses *Sporobolus virginicus* and *Xerochloa imbeberbis*, and emergent *Excoecaria agallocha*; in the background low shrubs of *Ceriops tagal* and *Avicennia marina* (high tidal zone, western Dampier Peninsula). B. Complex mangal vegetation appearing as "zones" on a broad tidal flat. C. Complex mangal vegetation appearing as "zones" of mangrove inhabiting a tidal gravel flat and abutting a slope covered with terrestrial vegetation. D. E. Sand ridge above the level of the highest tides and complex mangal vegetation in swales between ridges; leeward of sand ridge fringed by mangal. F. Rocky shore with mangrove. G. Dune crest: *Pandanus* with graminoids. H. *Spinifex longifolia* and other species on a foredune. I. Creeper *Canavalia rosea* and shrub *Thespesia populneoides* on limestone slab rubble of cyclone deposit just above the level of the highest tides. J. Edge of a high-tidal alluvial fan; foreground of grasses with scattered shrubs of *Avicennia marina*, far-ground of complex mangal with *Avicennia marina*, *Ceriops tagal*, and *Bruguiera exaristata*.

expressed at the coast. While the system may appear floristically simple, the expression of the vegetation in these habitats is much more complicated than that presented by Hnatiuk & Kenneally (1981).

Discussion

The review above, the description of habitats, and analysis of vegetation with respect to habitat types, illustrate richness of flora and vegetation in the coastal Kimberley region.

Coastal habitats, as described in this paper, are variable in landscape, sediments and soils, and are subject to inundation and to waters of salinity ranging from freshwater, marine to hypersaline. Further, they are exposed to sea spray, to coastal winds, and to salt-laden winds. Additionally, they exhibit temporal variation. While inland habitats manifest long term (geological) stability, coastal habitats can be sedimentologically-built, removed, or substantially modified in the short term, and very short term due to wind, tides, waves, and storms. With coast dynamics and coastal processes, the salinity regimes maintaining coastal vegetation also can be markedly altered in the short term. The coastal zone is the zone of mixing between terrestrial freshwater, brackish water, sea water and evaporation-concentrated sea water, providing a wealth of interactions. Effectively, because of spatially and temporally variable landscape, sediments/soils, and hydrochemistry, the coastal vegetation habitats are the most complex habitats in the Kimberley region and, yet, least explored botanically.

Our use of habitat/floristic variation/vegetation expression forms a useful tool to describe the variation in coastal systems of the Kimberley, as well as providing a platform for monitoring and further research. In terms of conservation, the system we have exposed allows informed choices for coastal land and sea use to be made. The full implementation of our approach to documenting coastal vegetation provides an understanding of both temporal and spatial variation in vegetation, such that future conservation choices should not necessarily be restricted to areas that are apparently rare or restricted in a spatial sense; rather it allows for a more dynamic approach to conservation planning and especially management.

Current Conservation status of the coastal vegetation in the Kimberleys

The existing conservation reserves containing coastal vegetation in the Kimberley region are the Mitchell River National Park and the Prince Regent Nature Reserve. Much of the remaining coastline north of King Sound is included within extensive Aboriginal lands which are managed by the Traditional Owners to ensure ecological values are maintained.

In 2009 the Western Australian government announced the Camden Sound Marine Park for marine conservation containing the St George Basin estuary system to the high water mark including extensive mangrove forests adjacent to the Prince Regent Nature Reserve. The St George Basin estuarine environment is heavily influenced by freshwater flow from the Prince Regent River which runs almost entirely straight along a fault or fracture through the King Leopold Sandstone. The final decision on the proposed marine park had not been made as at the end of February 2011.

In 2008 the Australian and Western Australian governments agreed to undertake an assessment of the west Kimberley including coast areas to identify its National Heritage (and potential international heritage) values. Subsequently the Australian Heritage Council (AHC) undertook an assessment of the west Kimberley to determine those areas with National Heritage values, for possible inclusion in the National Heritage listing under the Environment Protection and Biodiversity Conservation Act 1999, which would provide recognition and protection of any outstanding heritage values in the west Kimberley. The AHC's preliminary assessment noted that the spectacular west Kimberley coast (from King Sound near Derby to Bonaparte Gulf near Wyndham) is the longest stretch of predominantly rocky coast in Australia (Brocx & Semeniuk 2011) being a drowned river landscape including headlands and archipelagos, deep bays, impressive tidal effects and waterfalls, undisturbed by major coastal infrastructure. Moreover it found that 'contemporary refugia, such as the Kimberley, can be regarded as 'natural laboratories' for the study of ecological and evolutionary processes. The coast and islands, vine thickets, mangroves, karst areas and northern and western rivers are particularly important for protecting species and ecosystems which are rare, unknown or threatened elsewhere'.

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